

## CLAIMS

1. An electrochemical cell, comprising:  
a first terminal material including at least one magnesium ion; and  
a second terminal material including a rutile structure capable of intercalating said at least one magnesium ion.
2. The electrochemical cell of claim 1, wherein said rutile structure comprises a crystalline structure that includes a compound having the formula  $M_xO_2$ , wherein M represents a metal atom.
3. The electrochemical cell of claim 2, wherein said crystalline structure is an active material and said formula is  $TiO_2$ .
4. The electrochemical cell of claim 3, wherein electrons from said at least one magnesium ion are transferred to Ti and  $O_2$  of said  $TiO_2$ .
5. The electrochemical cell of claim 1, wherein said rutile structure is electrically conductive and ionically conductive.
6. The electrochemical cell of claim 1, wherein said rutile structure intercalates said at least one magnesium ion at an octahedral site of a unit cell of said rutile structure.
7. The electrochemical cell of claim 1, wherein an energy of insertion for intercalating said at least one magnesium ion into said rutile structure is 1.81 eV, and a voltage of said electrochemical cell is 0.9 V.
8. The electrochemical cell of claim 1, wherein said rutile structure expands by one percent when a concentration

of 0.0625 magnesium ions per molecule of said rutile structure exists in said electrochemical cell, and said rutile structure expands by ten percent when a concentration of 0.5 magnesium ions per molecule of said rutile structure exists in said electrochemical cell.

9. The electrochemical cell of claim 1, wherein when said at least one magnesium ion has been intercalated into said rutile structure, the at least one magnesium ion has a charge of 1.74 e.

10. The electrochemical cell of claim 1, wherein said rutile structure comprises at least one nanoparticle and carbon as a mixture.

11. The electrochemical cell of claim 10, wherein said at least one nanoparticle is substantially round and has a diameter of between 100 nm and 1000 nm.

12. The electrochemical cell of claim 11, wherein said at least one nanoparticle is substantially round and has a diameter of 100 nm.

13. The electrochemical cell of claim 10, wherein said at least one nanoparticle is substantially round and has a diameter of between 30 nm and 70 nm.

14. The electrochemical cell of claim 13, wherein said at least one nanoparticle is substantially round and has a diameter of 50 nm.

15. The electrochemical cell of claim 10, wherein said at least one nanoparticle is an elongated fiber.

16. The electrochemical cell of claim 10, wherein said at least one nanoparticle is reduced to increase electrical

conductivity.

17. The electrochemical cell of claim 1, wherein said first terminal material is at an anode and said second terminal material is at a cathode.

18. The electrochemical cell of claim 17, wherein said anode comprises one of a carbon nanotube, a graphite structure, titanium disulfide,  $\text{MgZn}_2$  and  $\text{MgCu}_2$ .

19. The electrochemical cell of claim 1, wherein said electrochemical cell is rechargeable.

20. The electrochemical cell of claim 1, further comprising an electrolyte that includes one of:

(a)  $\text{Mg}(\text{ClO}_4)_2$  in one of (i) a propylene carbonate  $(-\text{OC}(\text{O})\text{OCH}(\text{CH}_3)\text{CH}_2-)$  solvent and (ii) an acetonitrile ( $\text{CH}_3\text{CN}$ ) solvent; and

(b)  $\text{Mg}[(\text{CF}_3\text{SO}_2)_2\text{N}]_2$  in one of (i) a tetrahydrofuran (THF) solvent having a chemical formula of  $-(\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{O})-$ , (ii) a dimethyl formamide (DMF) solvent having a chemical formula of  $(\text{CH}_3)_2\text{NCHO}$ , (iii) a butyrolactone solvent having a chemical formula of  $-(\text{OC}(\text{O})\text{CH}_2\text{CH}_2\text{CH}_2-)$ , and (iv) the propylene carbonate solvent.

wherein said electrolyte is interposed between said first terminal material and said second terminal material.

21. An electrode material for an electrochemical cell, wherein said electrode material has a rutile structure and is capable of intercalating at least one magnesium ion.

22. The electrode material of claim 21, wherein said rutile structure comprises a crystalline structure that includes a compound having the formula  $\text{M}_x\text{O}_2$ , wherein M represents

a metal atom.

23. The electrode material of claim 21, wherein said crystalline structure is an active material and said formula is  $\text{TiO}_2$ .

24. The electrode material of claim 22, wherein electrons from said at least one magnesium ion are transferred to Ti and  $\text{O}_2$  of said  $\text{TiO}_2$ .

25. The electrode material of claim 21, wherein said rutile structure is electrically conductive and ionically conductive.

26. The electrode material of claim 21, wherein said rutile structure intercalates said at least one magnesium ion at an octahedral site of a unit cell of said rutile structure.

27. The electrode material of claim 21, wherein an energy of insertion for intercalating said at least one magnesium ion into said rutile structure is 1.81 eV, and a voltage of said electrochemical cell is 0.9 V.

28. The electrode material of claim 21, wherein said rutile structure expands by one percent when a concentration of 0.0625 magnesium ions per molecule of said rutile structure exists in said electrode material, and said rutile structure expands by ten percent when said a concentration of 0.5 magnesium ions per molecule of said rutile structure exists in said electrode material.

29. The electrode material of claim 21, wherein when said at least one magnesium ion has been intercalated into said rutile structure, the at least one magnesium ion has a charge of 1.74 e.

30. The electrode material of claim 21, wherein said rutile structure comprises at least one nanoparticle and carbon as a mixture.

31. The electrode material of claim 30, wherein said at least one nanoparticle is substantially round and has a diameter of between 100 nm and 1000 nm.

32. The electrode material of claim 31, wherein said at least one nanoparticle is substantially round and has a diameter of 100 nm.

33. The electrode material of claim 30, wherein said at least one nanoparticle is substantially round and has a diameter of between 30 nm and 70 nm.

34. The electrode material of claim 33, wherein said at least one nanoparticle is substantially round and has a diameter of 50 nm.

35. The electrode material of claim 30, wherein said at least one nanoparticle is an elongated fiber.

36. The electrode material of claim 30, wherein said at least one nanoparticle is reduced to increase electrical conductivity.

37. The electrode material of claim 21, wherein said electrode material is at a cathode.

38. The electrode material of claim 21, wherein said electrochemical cell is rechargeable.

39. The electrode material of claim 21, wherein the at least one magnesium ion is received from an anode material that stores the at least one magnesium ion.

40. The electrode material of claim 39, wherein said

anode material comprises one of a carbon nanotube, a graphite structure, titanium disulfide,  $\text{MgZn}_2$  and  $\text{MgCu}_2$ .

41. A rechargeable electrochemical cell, comprising:  
an anode configured to store at least one magnesium ion; and

a cathode comprising a rutile structure configured to intercalate said at least one magnesium ion.

42. The rechargeable electrochemical cell of claim 41, wherein said rutile structure comprises a crystalline structure that includes a compound having the formula  $\text{M}_x\text{O}_2$ , wherein M represents a metal atom.

43. The rechargeable electrochemical cell of claim 42, wherein said crystalline structure is an active material and said formula is  $\text{TiO}_2$ .

44. The rechargeable electrochemical cell of claim 43, wherein electrons from said at least one magnesium ion are transferred to Ti and  $\text{O}_2$  of said  $\text{TiO}_2$ .

45. The rechargeable electrochemical cell of claim 41, wherein said rutile structure is electrically conductive and ionically conductive.

46. The rechargeable electrochemical cell of claim 41, wherein said rutile structure intercalates said at least one magnesium ion at an octahedral site of a unit cell of said rutile structure.

47. The rechargeable electrochemical cell of claim 41, wherein an energy of insertion for intercalating said at least one magnesium ion into said rutile structure is 1.81 eV and a voltage of said electrochemical cell is 0.9 V.

48. The rechargeable electrochemical cell of claim 41, wherein said rutile structure expands by one percent when a concentration of 0.0625 magnesium ions per molecule of said rutile structure exists in said rechargeable electrochemical cell, and said rutile structure expands by ten percent when a concentration of 0.5 magnesium ions per molecule of said rutile structure exists in said rechargeable electrochemical cell.

49. The rechargeable electrochemical cell of claim 41, wherein when said at least one magnesium ion has been intercalated into said rutile structure, the at least one magnesium ion has a charge of 1.74 e.

50. The rechargeable electrochemical cell of claim 41, wherein said rutile structure comprises at least one nanoparticle and carbon as a mixture.

51. The electrode material of claim 50, wherein said at least one nanoparticle is substantially round and has a diameter of between 100 nm and 1000 nm.

52. The electrode material of claim 51, wherein said at least one nanoparticle is substantially round and has a diameter of 100 nm.

53. The electrode material of claim 50, wherein said at least one nanoparticle is substantially round and has a diameter of between 30 nm and 70 nm.

54. The electrode material of claim 53, wherein said at least one nanoparticle is substantially round and has a diameter of 50 nm.

55. The rechargeable electrochemical cell of claim 50, wherein said at least one nanoparticle is an elongated fiber.

56. The rechargeable electrochemical cell of claim 50, wherein said at least one nanoparticle is reduced to increase electrical conductivity.

57. The rechargeable electrochemical cell of claim 41, further comprising an electrolyte that includes one of:

(a)  $\text{Mg}(\text{ClO}_4)_2$  in one of (i) a propylene carbonate  $(-(\text{OC}(\text{O})\text{OCH}(\text{CH}_3)\text{CH}_2)-)$  solvent and (ii) an acetonitrile  $(\text{CH}_3\text{CN})$  solvent; and

(b)  $\text{Mg}[(\text{CF}_3\text{SO}_2)_2\text{N}]_2$  in one of (i) a tetrahydrofuran (THF) solvent having a chemical formula of  $-(\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{O})-$ , (ii) a dimethyl formamide (DMF) solvent having a chemical formula of  $(\text{CH}_3)_2\text{NCHO}$ , (iii) a butyrolactone solvent having a chemical formula of  $-(\text{OC}(\text{O})\text{CH}_2\text{CH}_2\text{CH}_2)-$ , and (iv) the propylene carbonate solvent.

wherein said electrolyte is interposed between said anode and said cathode.

58. The rechargeable electrochemical cell of claim 41, wherein said anode comprises one of a carbon nanotube, a graphite structure, titanium disulfide,  $\text{MgZn}_2$  and  $\text{MgCu}_2$

59. A method of manufacturing an electrode material for an electrochemical cell, comprising the steps of:

forming rutile nanoparticles having a shape and a size; and

enhancing electrical conductivity of said rutile nanoparticles by mixing said rutile nanoparticles to form a composite.

60. The method of claim 59, wherein said forming step comprises:

positioning the rutile powder in a  $\text{ZrO}_2$  (zirconia) pot;  
and

milling said positioned rutile powder into nanoparticles.

61. The method of claim 60, wherein said size of said rutile nanoparticles is between 100 nm and 1000 nm.

62. The method of claim 61, wherein said size of said rutile nanoparticles is 100 nm.

63. The method of claim 60, wherein said milling step comprises mechanically grinding said rutile powder by a planetary ball mill at between 500 revolutions per minute (rpm) and 1000 rpm for 3 to 12 hours.

64. The method of claim 63, wherein said mechanical grinding is performed at 700 rpm.

65. The method of claim 59, wherein said forming step comprises:

sealing the rutile powder in a quartz tube with an oxygen partial pressure of less than 0.01 bar of oxygen, to generate a reducing atmosphere;

annealing said sealed rutile powder at a temperature less than 400 degrees Celsius for a duration at least 6 hours; and

quenching said annealed rutile powder to a range of 0 to 30 degrees Celsius.

66. The method of claim 65, wherein said temperature of said annealing is between 300 and 400 degrees Celsius, and said duration of said annealing is 12 hours.

67. The method of claim 65, wherein said size of said rutile nanoparticles is 100 nm.

68. The method of claim 59, wherein said forming step

comprises:

synthesizing said rutile powder via a sol-gel/hydrothermal process, wherein nitric acid is used as a catalyst, and commercial titanium alkoxide is diluted by ethanol and added to water, to form a solution;

stirring the resulting solution for about two hours, filtering a precipitate, and adding said filtered precipitate into a concentrated nitric acid solution until the precipitate dissolves;

stirring the dissolved precipitate below 45 degrees Celsius for at least 24 hours, or until the rutile powder re-precipitates; and

filtering and drying said re-precipitated rutile powder at between 90 and 100 degrees Celsius.

69. The method of claim 68, wherein said size of said rutile nanoparticles is between 30 nm and 70 nm.

70. The method of claim 69, wherein said size of said rutile nanoparticles is 50 nm.

71. The method of claim 59, wherein said forming of said rutile nanoparticles is confirmed by x-ray diffraction (XRD) spectroscopy.

72. The method of claim 59, wherein said enhancing step comprises:

mixing said rutile nanoparticles with carbon and polyvinylidene fluoride (PVDF) having the chemical formula  $-(CH_2CF_2)_n$  to form a mixture having increased electrical conductivity;

pressing the mixture with a stainless steel mesh, which

acts as a current collector to form a composite electrode material; and

drying the composite electrode material under vacuum at room temperature for about 24 hours.